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The Cryosphere Discussions

Interactive comment on “Spatial structures in the heat budget of the Antarctic Atmospheric Boundary Layer” *by* W. J. van de Berg et al.

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First of all, we want to thank the reviewer for his valuable comments, which improves the clarity of the manuscript. Below we discuss the comments point-by-point.

Remark 1) *The definition of the boundary layer height (BLH) is crucial in this paper. After all, average terms of the heat budget over the depth of the boundary layer are discussed and presented throughout the paper. It is therefore necessary to evaluate the model ability to correctly represent the BLH compared to available measurements. This needs to be done using a consistent definition of the BLH in model and measurements. Moreover, I find it somewhat surprising that the authors choose to define the boundary layer as the level where the bulk Richardson number reaches 0.25 of its surface value (as is standard in the model) and modify this using an ad-hoc function given in Fig 4a. It seems that this function is chosen to get about the right order of*

magnitude. From the manuscript it is not at all clear that this new BLH satisfies the criteria given on page 278. I think it is more straightforward to use the modeled profiles to determine the BLH, and therefore directly satisfy the criteria given on page 278.
Answer: We have tried to use temperature, wind or SHF profiles for estimating the ABL depth, but we could not construct temporal and spatial coherent ABL depths with these parameters. For example, the temperature deficit vanishes over the ocean and can be less than 1 K in Antarctica during summer; the vertical wind pattern looses it katabatic signature over sea or around the domes of Antarctica; SHF profiles change sign over open water.
It should be noted that the ABL depth estimate provided by RACMO2/ANT is calculated within the physics package for post processing; it is not used for the calculation of any flux. An underestimated model diagnosed ABL depth does thus not imply an erroneous ABL dynamics. We have deliberately chosen to present vertical profiles to support our choice.

Remark 2) *Although the heat budget is discussed in detail, there is no discussion on how this would affect the near-surface temperature distribution. In the introduction is written: Analysis of the heat budget provides a tool to understand the processes that control the near-surface temperature in Antarctica. But is the small-scale variability in the horizontal and vertical heat advection really relevant for the current temperature distribution? A simple way to answer this question might be the following: One could perform a linear regression between the 2m potential temperature and surface elevation (possibly continentality could also be included). The predicted temperature could then be substracted from the modeled temperature (Fig 1). Subsequently the spatial variability in the different terms in the heat budget could be used to understand the temperature spatial distribution, corrected for differences in elevation. Does such a study confirm that the regions with subsidence are warmer than other regions of equal height where no subsidence takes place? It would also be interesting to include a quantitative estimate of the effect.*
Answer: Indeed we try to show how the heat budget relates to the temperature distri-

bution in Antarctica. However, this relation is not that simple by means of a significant correlation between temperature and a heat budget component. The analysis proposed by the reviewer shows only a significant negative correlation between LWD and inversion strength, which means that the near-surface air comes closer to radiative balance if the inversion increases in strength.
The relationship we describe in this manuscript is more complex. Since significant heat advection requires a temperature gradient along the prevailing wind, topography relates to the derivative of the temperature along ABL wind trajectories. We reworded the concerning sentences in the abstract in order to avoid the suggestion of a linear relation between temperature and advection:
“Horizontal advection balances excess warming caused by vertical advection, hence the temperature deficit in the ABL weakens over domes and ridges along the prevailing katabatic wind. Conversely, vertical advection is reduced in regions with concave topography, i.e. valleys, where the ABL temperature deficit enlarges along the katabatic wind.”

Remark 3) *“Horizontal advection" ($AdvH$) is derived along the hybrid eta-coordinate of the model. Therefore, $AdvH$ is not a horizontal advection, but is more closely related to the “along slope" advection. The vertical advection is approximately the advection perpendicular to the slope. This should be made clear especially in the abstract and conclusions.*
Some related issues: i) Page 281: Line 20: Warming by $AdvH$ is related to the deepening of the inversion layer. This statement needs to be worded more carefully: After all, there is also a contribution to the "horizontal" rise of free the atmosphere potential temperature towards the interior in Fig 7a due to increasing surface elevation in a stably stratified atmosphere.
ii) The spatial variability in $AdvH$ in the region of the Antarctic Peninsula and Marie Byrd Land region are related to orographic uplift. Since the atmosphere is stably stratified, uplift (downward motion) always leads to adiabatic cooling (warming). By using hybrid coordinates, this cannot be separated from horizontal advection (for example

TCD
1, S229–S235, 2007

Interactive Comment

the transport of relatively warm air from the west of the Peninsula to the east side). This information should be included in the manuscript, and I think it would also be a good idea to mention this in the figure captions where the spatial variability of $AdvH$ is shown.

Answer: When we first use of horizontal advection in the abstract, section 3.1 and the conclusion, we added the remark that horizontal means along-slope.

Ad i) In the interior of Antarctica, the higher free atmosphere potential temperatures due to increasing elevation is almost entirely balanced by lower potential temperature due to increasing continentally. In the free atmosphere above Antarctica, potential temperature isopleths are thus almost parallel to the surface. Therefore, deepening of the ABL primarily is responsible for the positive value of $AdvH$. Along the coast, this elevation effect is indeed important. We clarified this in the discussion of Figure 7(a):

"...As a result, the rise of free the atmosphere potential temperature towards the interior is due to increasing surface elevation in a stably stratified atmosphere. In the interior, however, this effect is almost balanced by the effect of decreasing latitude; potential temperature isopleths are thus almost parallel to the surface.",

and the discussion of Figure 7(c) on this point:

"...In the interior of Antarctica, warming by $AdvH$ is related to the deepening of the inversion layer. ..."

Ad ii) We have added to section 4.3 that the atmosphere is stably stratified: ?The coast of West Antarctica and the western side of the Antarctic Peninsula experience cooling by $AdvH$ due to diabatic uplift in a stably stratified atmosphere.? However, if stratification is the sole reason for the $AdvH$ patterns, the warming east of the Peninsula should balance the cooling west of the Peninsula, which is not the case. Therefore, condensation is important. Examples of balancing patterns can be found along the coast of Dronning Maud Land. The figure captions have been adjusted.

Remark 4) *In the abstract it is written that: meso-scale (about 10 km) topographic structures have thus a strong impact on the ABL winter temperature. This seems in contrast with what is written in the manuscript: $AdvV$ reaches its extreme positive values in val-*

leys and ridges with length scales of 100 km. (Page 282; line 16). Moreover (as indeed recognised by the authors on page 282) the effective model grid spacing is about 4 times the model grid spacing (so 200 km). The patchy structures in Fig 8, 9 and 11, with typical length scale in the order of this effective model grid spacing, is therefore likely to be related to the grid spacing used and not necessarily a phenomenon with a physical meaning. I therefore think that it is inappropriate to mention such a length scale in the abstract. Furthermore, it cannot be excluded that smaller scale structures appear when the grid spacing of the model decreases. An extension of the discussion on this issue is needed.

Answer: Unfortunately, a typo came in the abstract, the length scale should be 100 km, not 10 km, but we removed the number in the abstract. We extended the discussion on the most determining length scales in section 4.3 and the discussion:

"As for $AdvV$, extreme values of $AdvH$, and thus the largest along-slope temperature gradients, are found at topographic structures with length scales in the order of 100 km. On the other hand, larger features may have a smaller temperature gradient, but provide a longer path for $AdvH$ to act on temperature." (section 4.3)

"The extremes of $AdvV$ and $AdvH$ are found at topography with a length scale of 100 km, the minimum size of topography that was properly resolved. ABL temperature, however, is also influenced by larger features, because larger features provide a longer path for $AdvH$ to act on temperature." (discussion)

Remark 5) *The comparison between modelled TOA net radiation and ISCCP data indeed shows a good correspondence for winter but there are also some small deficiencies namely: i) an overestimation in the region with the highest elevation and ii) an underestimation at the steep slopes around the ice shelves, and to a lesser extent on the ice shelf. Do you know the reason for this deficiency? (surface temperature, temperature profile, clouds?)*

Answer: Winter surface temperature is well modeled by RACMO2/ANT, but a small (1 K) cool bias is found in the troposphere, as well as indications for too few clouds and underestimated LW emissivity, but these deviations likely interact. Additional evaluation

TCD

1, S229–S235, 2007

Interactive Comment

of model data would be required to assess the reason of these deficiencies.

Remark 6) Page 281: line 14 *The near surface warming at the ice sheet margin is related to the persistently large temperature difference between the ice shelf and the ocean. I do not understand this argument: Vertical advection can only take place when a vertical potential temperature gradient is present. Such a strong vertical potential temperature gradient is not represent in Fig 7a. Please explain.*
Answer: Since $AdvV$ includes diffusion (K), this pattern is due to diffusion of the horizontal temperature difference between land and ocean. This notion is added to the text.

Remark 7) Fig 7c: *Please show the meridional wind in this figure. After all, this component determines, together with the meridional temperature gradient, which is already shown, the meridional horizontal heat transport. The zonal wind component is already shown in Figure 7(a). Is the zonal heat transport negligible?*
Answer: In Antarctica, along-slope is nearly meridional; cross-slope is nearly zonal. The zonal/cross-slope wind is not shown in Figure 7. The horizontal heat advection is mainly due to the along-slope wind and temperature differences, which are shown in Figure 7(a). On continental scales zonal heat advection is small, but the zonal heat flux is far greater than the meridional and vertical heat flux.

Remark 8) Page 284: Line 28: *"Convex topographic features have a weak inversion." I think this statement is not correct: in case of convex topography, subsidence takes place. In absence of other processes, subsidence leads to a strengthening of the inversion, rather than a weakening.*
Answer: In absence of any other process continuous subsidence will eventually lead to a neutral temperature profile. The statement 'convex topographic features have a weak inversion' implies that a stronger subsidence lowers the top of the inversion deficit layer, which increases temperature gradients in the ABL. So, given a katabatic wind, SHF increases, rising the surface temperature (thus decreasing SHF), until a new balance is found between SHF and net LW emission; a balance with a weaker inversion.

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TCD

1, S229–S235, 2007

Interactive Comment